Ultrasonic Characterization of Mustard Oil: Velocity, Compressibility and Impurity Sensitivity

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Abstract: In the present study, an effort has been made to examine the ultrasonic wave propagation in mustard oil using a piezoelectric generator-based ultrasonic interferometer under the appropriate controlled conditions. The investigation determines both ultrasonic velocity and adiabatic compressibility, revealing that mustard oil shows significantly higher velocity (1600 m/s) and lower compressibility (4.24×10^{-10} N/m^2) than distilled water. These results point out to enhanced molecular cohesion and denser structure in mustard oil. By substitution of varying different amount of concentrations of distilled water, the study simulates impurity effects and obtains a consistent decline in ultrasonic velocity in conjunction with a rise in compressibility, emphasizing the technique's sensitivity to compositional changes. Unlike the prior studies focusing largely on acoustic behavior in pure liquids, this research highlights the dynamic responsiveness of ultrasonic parameters to purity variations, positioning ultrasonic interferometry as a suitable, non-invasive device for rapid quality control and adulteration detection in edible oils. The ability to interconnect with physicochemical properties to ultrasonic behavior, they offer valuable insights for the food and oil processing industries. Moreover, the novelty lies in quantitatively correlating adulteration levels with acoustic responses in an industrially relevant oil, putting the groundwork for extensive applications in purity certification and functional analysis of consumable oils.

Keywords: Ultrasonic wave, mustard oil, adiabatic compressibility, ultrasonic interferometer, impurity analysis.

I Introduction

In recent years, growing awareness about food quality and safety—particularly in edible oils—has underscored the need for rapid, non-destructive techniques capable of evaluating purity and composition with high precision. Mustard oil, widely used in culinary and traditional medicinal applications, is especially prone to adulteration for economic gain. Due to their fluid nature, edible oils are often blended with lower-quality substitutes that closely mimic their appearance but lack comparable nutritional and therapeutic value. Visual inspection alone is insufficient to detect such adulterants, creating an urgent demand for more reliable and efficient analytical methods to ensure the authenticity and quality of mustard oil. Among non-destructive testing (NDT) techniques, ultrasonic testing stands out for its ability to analyze materials without altering their physical or chemical properties. Ultrasonic waves consist mechanical waves with frequencies above 20 kHz that require a propagation medium and are highly sensitive to changes in composition. The introduction of adulterants alters the physicochemical properties of pure mustard oil, resulting in measurable shifts in ultrasonic wave velocity. Since this velocity is influenced by both composition and temperature, it can be employed for the qualitative and quantitative detection of adulteration under varying thermal conditions. Moreover, ultrasonic velocity data serve as the basis for calculating important thermodynamic parameters, offering insights into molecular interactions and bonding behavior. Ultrasonic technology, due to its precision and responsiveness to structural variations, has also proven effective in the analysis of acidic media. Compared to conventional chemical methods—which often involve complex procedures and significant operational costs—ultrasonics offers a fast, cost-effective, and user-friendly alternative. More broadly,

ultrasonic techniques are widely used across disciplines to study the physical properties of gases, liquids, and solids. In liquids, in particular, ultrasonic wave propagation is crucial for exploring molecular dynamics, thermodynamic stability, and structural characteristics.

Mustard oil, composed of triglycerides, fatty acids, and trace bioactive compounds, offers a rich medium for ultrasonic analysis. Parameters such as velocity and adiabatic compressibility, when measured accurately, can reveal the bulk behavior and molecular integrity of the oil. The velocity of sound in a fluid depends on its density and elasticity—both shaped by temperature, pressure, and molecular arrangement. Adiabatic compressibility, derived from velocity data, quantifies the fluid's resistance to volume change under adiabatic conditions and serves as a key indicator of structural cohesion. Numerous studies have examined the ultrasonic behavior of liquids, especially edible oils, to evaluate their physicochemical properties [1–3]. Researchers have investigated the impact of molecular architecture and intermolecular forces on acoustic parameters [4–7], along with the effects of temperature and compositional variability [8–10]. Mustard oil, rich in monounsaturated and polyunsaturated fatty acids, presents a distinct case for exploring the sensitivity of ultrasonic waves to structural and compositional changes. Today, ultrasonic analysis of mustard oil is attracting attention for its dual significance ensuring food quality and expanding the understanding of fluid-state acoustics. Its non-invasive ability to assess purity, molecular dynamics, and thermodynamic behavior makes it a valuable tool in both industrial and academics [11–17].

In the present study, we aim to investigate the impact of distilled water adulteration in mustard oil on its ultrasonic velocity and adiabatic compressibility.

II Materials and Methods

A commonly old traditional approach has been used to extract the mustard oil from the seeds. Traditionally, mustard oil was extracted using a cold-press method, commonly known as *ghani* or *kolhu*. In this process, cleaned and sun-dried mustard seeds were slowly crushed in a wooden or stone mill powered manually or by animals. The oil would gradually seep out during pressing and was collected without applying heat or chemicals. After extraction, it was filtered through cloth to remove seed residues. This method preserved the oil's natural flavor, aroma, and nutritional value, though it yielded less oil compared to modern techniques. It remains in use in some rural areas for its purity and traditional appeal [18]. Distilled water was collected from the chemical lab.

II.a Mustard Oil

Mustard oil is derived from the seeds of several mustard species, including *Sinapis alba* L. (white or yellow mustard), *Brassica nigra* L. Koch (black or true mustard), and *Brassica juncea* L. Czern. et Cosson (Indian or oriental mustard). These plants belong to the *Brassicaceae* family. *Brassica juncea*, commonly known as Indian mustard or mustard greens, is a perennial herb often grown as an annual or biennial crop.

II.a.1 Physicochemical Properties

The quality and suitability of mustard oil for consumption are determined by its physical and chemical properties, including density, viscosity, boiling point, saponification value (SV), iodine value (IV), and peroxide value (PV). These parameters are essential for assessing the oil's nutritional profile and stability. A key component of mustard oil is allyl isothiocyanate, which comprises approximately 92% of its composition. This compound is responsible for the oil's characteristic pungency and can be toxic if consumed in excessive amounts. Mustard seeds are rich in various bioactive compounds. They contain phytoalexins such as sinalexin and sinalbins A and B; sterols like sitosterol and campesterol; and flavonoids including apigenin and chalcone. The seed mucilage consists predominantly of carbohydrates (80%–94%), along with minor amounts of ash (1.7%–15%) and protein (2.2%–4.4%). The sharp

flavor of mustard seeds originates from glucosinolates that are sulfur-containing compounds. They are biologically inactive in their native form. When the seeds are crushed, the enzyme myrosinase converts glucosinolates into isothiocyanates, which contribute to both the pungency and therapeutic properties of mustard oil. Sinalbin imparts the milder flavor typical of white mustard, whereas sinigrin is associated with the more intense taste of black mustard. Beyond flavor, glucosinolates exhibit antibacterial, antifungal, and anticancer properties, enhancing the medicinal value of mustard oil. In addition, mustard oil contains about 30% protein and is a source of calcium, phytins, phenolics, and natural antioxidants.

In this study, ultrasonic velocity and adiabatic compressibility were calculated for distilled water in the mustard oil with varying impurity percentages (5%, 10%, 15%, 20%, and 25%) by using the device the ultrasonic Interferometer.

II.b Ultrasonic Interferometer

An ultrasonic interferometer (Figure 1) is a precision device (shown in fig. 1) used to measure the velocity of ultrasonic waves in liquids, enabling the determination of important physical properties such as adiabatic compressibility. The instrument operates on the principle of generating standing waves within the liquid medium, achieved by superimposing incident and reflected ultrasonic waves. These standing waves create pressure variations, which are analyzed to determine wave velocity. The core components of the interferometer include a high-frequency oscillator (typically 1–5 MHz) to generate ultrasonic waves, a measuring cell with a quartz crystal transducer at the base, a movable reflector to establish standing wave patterns, a micrometer screw for fine positional adjustments, and a voltmeter to monitor amplitude changes.

Figure 1: Ultrasonic Interferometer

During operation, the liquid sample of impurity (different concentrations) is introduced into the measuring cell, taking care to avoid air entrapment. After setting the desired frequency, the reflector is adjusted using the micrometer screw to locate successive pressure maxima. The distance between these maxima corresponds to half the wavelength of the wave. Using the relation $v = \lambda f$, where v is the ultrasonic velocity, λ is the wavelength, and f is the frequency, the velocity of sound in the

liquid is calculated. Furthermore, Adiabatic compressibility (β_s), a measure of a fluid's resistance to compression under adiabatic conditions, is then derived from the velocity data. It is inversely related to the bulk modulus and offers valuable insight into the molecular structure and interactions within the fluid.

III Results and Discussion

Figure 2 illustrates the variation of ultrasonic velocity in mustard oil and distilled water. The mustard oil exhibits a significantly higher ultrasonic velocity (1600 m/s) than distilled water (1484 m/s), indicating denser molecular packing and stronger intermolecular forces. This enhanced acoustic response is attributed to the presence of long-chain triglycerides and fatty acids, which increase the bulk modulus and reduce compressibility in the medium.

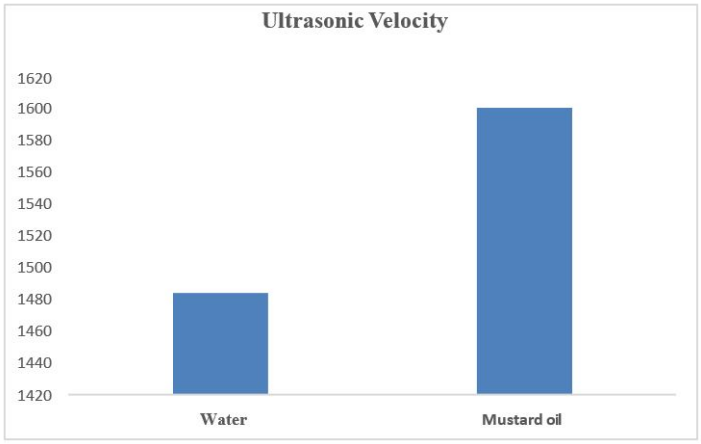

Figure 2: Ultrasonic Velocity in Mustard Oil and Distilled Water

Figure 3 shows the variation of adiabatic compressibility of mustard oil and distilled water. From the plot, it has been observed that the variation in adiabatic compressibility between mustard oil and distilled water. Mustard oil exhibits a significantly lower compressibility, approximately 4.24×10^{-10} N/m^2, compared to distilled water (4.55×10^{-10} N/m^2), indicating its greater resistance to volume change under applied pressure in the appropriate conditions. This reduced compressibility highlights the higher molecular rigidity and stronger intermolecular cohesion characteristic of mustard oil.

Figure 4 depicts the variation of ultrasonic velocity and adiabatic compressibility in mustard oil with increasing impurity levels. As the concentration of impurities (distilled water) rises from 5% to 25% in mustard oil, the ultrasonic velocity decreases linearly from 1580 m/s to 1500 m/s (black curve). This reduction is attributed to the disruption of molecular interactions by water molecules, which reduce the bulk modulus and enhance the medium's elasticity. Concurrently, a noticeable increase in adiabatic compressibility is observed, with values increasing from 4.4×10^{-10} N/m^2 at 5% impurity to 4.8×10^{-10} N/m^2 at 25%. [19] previously reported a ultrasonic velocity of 1440 m/s for mustard oil at 30 °C and at 30 °C, mustard oil exhibited an adiabatic compressibility of 4.15×10^{-10} N/m, as observed by [20]. This trend strongly indicates that the mixture becomes easier to compress as water content disrupts the dense molecular structure of mustard oil, reducing its resistance to compression.

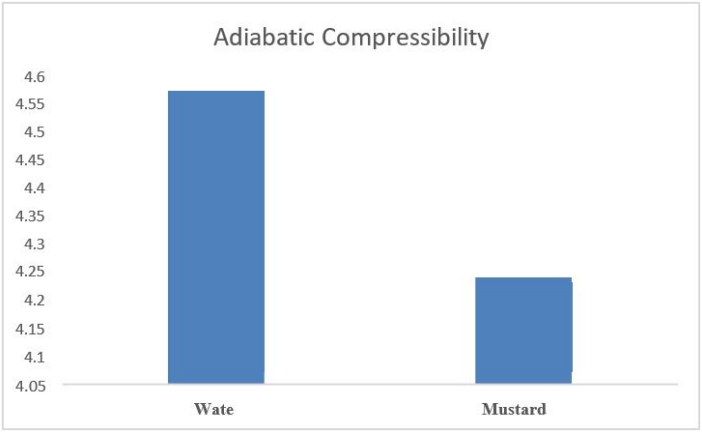

Figure 3: Adiabatic Compressibility of Mustard Oil and Distilled Water

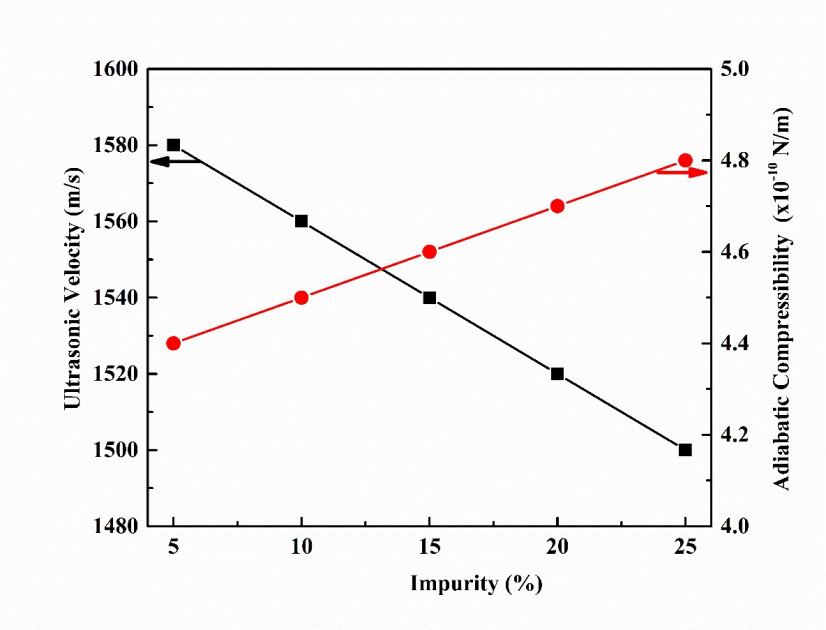

Figure 4: Variation of Ultrasonic Velocity and Adiabatic Compressibility vs Impurities in Mustard Oil

IV Conclusion

Food safety and authenticity have become one of the major concerns today, particularly with the rising issue of adulteration in edible oils. The current study addresses that challenge by offering a modest and reliable approach to check oil quality by employing ultrasonic technology. This study explored the propagation of ultrasonic waves through mustard oil, focusing on its velocity and adiabatic compressibility under controlled conditions and in the presence of varying impurities. The findings demonstrated that mustard oil exhibits higher ultrasonic velocity (1600 m/s) and lower adiabatic compressibility (4.24×10^{-10} N/m^2) compared to distilled water, indicative of stronger molecular interactions and a denser structure. The introduction of impurities, modeled by adding distilled water, led to a linear decrease in velocity and a corresponding increase in compressibility, highlighting the sensitivity of ultrasonic properties to compositional changes.

These results highlight the potential of ultrasonic techniques for non-destructive quality assessment, purity monitoring, and physicochemical characterization of edible oils, offering valuable applications in the food and oil industries. Unlike traditional lab tests that take time and may damage the sample, this method is quick, non-destructive, and based on how sound waves behave in the oil. It allows real-time detection of impurities, making it a practical and affordable option for ensuring oil purity and protecting consumers. Future research could extend these findings by examining temperature effects and exploring other oils for comparative analysis.

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